Galileo Images of a Region of Transitional Terrain on Ganymede: Preliminary Analysis.

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During its second close encounter with Ganymede, the Galileo SSI instrument imaged a region that is transitional from the dark terrain of northern Marius Regio to the bright grooved terrain of Nippur Sulcus. These 190 m/pixel images reveal a complex sequence of extensional and strike-slip structural deformation as furrowed dark terrain undergoes a transition to grooved terrain.

Observation objectives. The imaged area contains a region of furrowed terrain in Marius Regio along the boundary with Nippur Sulcus and has been disrupted into small polygonal blocks by a branching network of throughgoing grooves (Figure 1). Voyager 2 images (e.g. 20635.37) suggest that several of the blocks have been resurfaced by bright material of possible cryovolcanic origin [1]. The Galileo images provide information about furrow morphology, the early stages of dark terrain breakup, groove morphology, and the emplacement of light material. Four images were acquired at 190 m/pixel, and portions these frames were downlinked at an average compression of 7.5:1 to form the image mosaic. (For target placement see the planning image at http://www.jpl.nasa.gov/galileo/sepo/atjup/ganymede/GG2TRANS.html.)

Dark terrain, furrows, and fractures. Dark terrain in this portion of northern Marius Regio can be divided into dark furrowed material (df) in the northern portion of the mosaic, and younger dark material of a p3 palimpsest across the southern portion [1]; both of these materials pre-date grooved terrain formation. Galileo images show that the dark furrowed material can be divided into smooth and tectonically disrupted units. The relatively smooth unit displays some very subdued craters; a likely agent of degradation is bombardment from subsequent impacts as well as mantling by ejecta from ancient large impacts such as those which formed palimpsests. Other areas of the dark furrowed material contain subdued scarps and fresher appearing, but discontinuous, ridges and troughs of small scale (~2 km spacing) that are similar in trend and scale to structures within nearby grooved terrain. Subdued scarps are probably the oldest tectonic features in the region, while the fresher appearing small-scale ridges and troughs in the tectonically disrupted dark terrain likely predate grooved terrain formation only slightly. This unit also contains furrows ~10 km wide which are comprised of small scale troughs (~1 km spacing) that are subparallel to anastomosing in plan view. These broad furrows trend ~N15E (corresponding to the "arcuate" or System I furrows of [1,2]) and ~N30E and clearly predate grooved terrain formation, as they are superposed (and can be deformed by) bright materials and grooves of throughgoing grooves and grooved terrain.

Dark terrain of the p3 palimpsest region is fractured by troughs displaying four principal orientations and a range of scales. The largest trough in this dark terrain region is a ~5 km wide furrow oriented ~N15E (likely belonging to System I of [2]), showing a graben-like morphology and relatively fresh appearing bright walls. Other fracture sets are comprised of troughs generally ≤2 km wide, trending ~N45W and ~N20W, similar to the trends of "orthogonal" furrows and "oblique" (System II) furrows, respectively, of [1,2]. The least prominent, most narrow fractures in the region are near the limit of resolution and show ~N45E trends. Relatively long dark terrain troughs generally anastomose in trend, their segments mimicking those of the three most prominent fracture systems. Thus, it is likely that troughs have grown in length through coalescence of shorter troughs that belong to each of the three prominent fracture systems. Narrow knobs of terrain left as "islands" between closely spaced or intersecting troughs appear bright, and so regions of dark terrain that are the most dissected by troughs appear brightest. This suggests a scenario in which the dark material of dark terrain is only a thin veneer which can shed downslope into topographic lows to reveal clean icy material beneath. This is consistent with high resolution SSI observations of Galileo Regio, where there is direct evidence for downslope movement of dark material [Prockter et al., this volume].

Chains and clusters of craters appear in the southern portion of the mosaic, consisting of craters up to ~10 km in diameter. These are interpreted as secondary craters, presumably derived from the large p2 palimpsest to the southeast of the imaged area. A long and narrow (~50 x 1 km) extremely linear feature crosses the southeastern image and terminates as a series of coalesced pits at its southeastern extent. This feature does not appear to be radial to Ganymede's major basins and may be the product of a split impactor, or possibly the surface manifestation of a dike intrusion.

Transitional and Bright Terrain. Throughgoing grooves that appear to be transitional from dark terrain to grooved terrain trend generally NW across the mosaic. In detail, their bends mimic the NW and WNW trends of dark terrain fractures, suggesting an inheritance of structural trend. The most prominent throughgoing groove lane displays relatively prominent, dark floored troughs along its margins and shows parallel ridges and grooves within it, some of which are left-stepping en echelon. These en echelon features and those along the lane's central western margin are consistent with right-lateral shear along this feature. Strike-slip offsets are probably ~10 km at most, judging from the limited displacement of pre-existing structures. A bright rectangular region ~50 x 30 km in size is centered on a bend along this lane (in the northwest corner of the mosaic) and is flanked within the adjacent dark terrain by left-stepping en echelon structures. This bright region is interpreted as a pull-apart zone (rhombochasm) located at the releasing bend of a strike-slip structure. As a transtensional pull-apart zone, this region may have been a focus of local melt extrusion, making this bright patch a good candidate for a site of cryovolcanism. No flow fronts are apparent, however, suggesting extrusion of a low viscosity melt.

An ~85 x 50 km lozenge-shaped region in the center of the mosaic shows zones of ridges and grooves along and subparallel to its margins and has a central region which appears heavily disrupted. This region bears some resemblance to lozenge-shaped slivers between segments of the San Andreas fault, and similarly may have rotated in a shear couple. The sense of its lozenge shape suggests counterclockwise rotation of the block during its deformation. Its boundaries mimic the trends of fractures and furrows in dark terrain, so strike-slip motion may have proceeded along pre-existing dark terrain structures during its formation. Its relatively high albedo suggests that this block may have been resurfaced cryovolcanically before or during deformation. North of the lens-shaped region, bright terrain transforms gradually to dark terrain over a distance of at least 10 km, and the shape of the brightened zone mimics the shape of the lensoid deformed region. This transition suggests that tectonic deformation, rather than or in addition to cryovolcanism, could be brightening the terrain, perhaps through a change in the material or scattering properties of the fractured surface. No specific evidence is seen for pyroclastic mantling [3] as a brightening agent associated with the emplacement of bright terrain.

Some troughs that define isolated polygons show a prominent ridge within them, subparallel to their trends. These might be relatively undeformed surfaces (horsts) or prominent tilt block ridges, but a transpressional origin is also possible. Some candidate T-terminations [4] of newer structures against older ones can be identified NE of the central lozenge; however, an alternative history is that cryovolcanic material or tectonic resurfacing [Head et al., this volume] obliterated a continuation of these structures into adjoining blocks. Some pre-existing structures are apparently preserved within subsequently isolated blocks. Motion on the principal bounding structures likely continued until late in the transition process, as these structures cross-cut most surrounding features.

Structural interpretation. A range of ridge and trough morphologies and scales are seen across this transitional region between the dark terrain of Marius Regio and the bright grooved terrain of Nippur Sulcus. An emerging interpretation is that this represents a sequence in which dark terrain transitions to bright grooved terrain in the following way: (a) ancient dark terrain is fractured along furrows, and younger dark terrain palimpsest material breaks apart along preferred directions in a fashion of distributed deformation, (b) extension and shear deformation cause the propagation and linkage of pre-existing structures of various trends, concentrating tectonic deformation along a few prominent structures, which brighten as dark material sheds downslope into topographic lows (c) continued extension and shear motion along prominent structures concentrates tectonic deformation in the intervening blocks, (d) localized cryovolcanism can be triggered simultaneously in tectonically favorable locations, such as along releasing bends of the structurally isolated blocks, further brightening the blocks, and (e) late-stage tectonism, as by motion along primary structures, causes fracturing and grooving of brightened blocks. This sequence contains elements of models previously proposed for the emplacement of Ganymede's grooved terrain [4,5], with important modifications regarding the structural relationships of faults, the timing of faulting, the relative importance of horizontal shear, and the role and timing of cryovolcanism [Pappalardo et al., this volume; Head et al., this volume].

The transitional region between Marius Regio and Nippur Sulcus suggests dissection of dark terrain by throughgoing grooves through reactivation of dark terrain furrows and fractures by means of extension and shearing. Intervening bright terrain is deformed through tectonism, and brightening of terrain apparently follows in areas of concentrated tectonic deformation, perhaps as cryovolcanism is triggered in structurally isolated blocks, and is accompanied by intense tectonic disruption which may also have the effect of brightening fractured terrain. A shear component of deformation allows ridge and groove structures to form at small angles to the primary bounding structures, a common characteristic of Ganymede's grooved terrain. Further analysis of this target site, as well as additional Galileo dark and bright terrain targets, will allow the transition from dark to bright terrain to be documented.

References. [1] Murchie, S.L. and J.W. Head, U.S.G.S. Map I-1966 (1989). [2] Murchie, S.L. and J.W. Head, *JGR 93*, 8795 (1988). [3] Helfenstein, Ph.D. thesis, Brown Univ., 1986. [4] Golombek, M.P., and M.L. Allison, *GRL 8*, 1139 (1981). [5] Murchie, S.L., et al., *PLPSC 17*, *JGR 91*, E222 (1986).

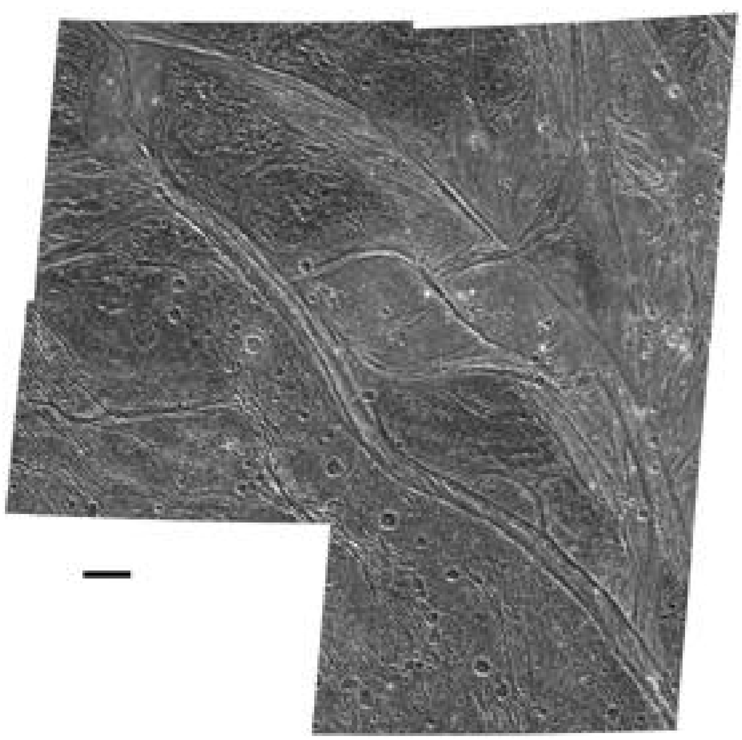

Figure 1. Mosaic of Galileo images (190 m/pxl) of a region that is transitional from furrowed dark terrain of Marius Regio (left) to bright grooved lerrain of Nippur Sulcus (right). Scale bar is 20 km; north is toward the top.